

# **Advanced Multifrequency Inversion Methods for Classifying Acoustic Scatterers**

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Award Number N00014-00-D-0122

## **LONG-TERM GOALS**

Our long-term goal is to improve methods for estimating zooplankton biomass by species and life-stage as a function of three-dimensional location and time.

## **OBJECTIVES**

The objective of this research program is to integrate sophisticated acoustic scattering models of zooplankton with mathematical inverse theory to develop advanced broadband and multiple-frequency methods that produce rapid and accurate results from bioacoustical field studies in a form that can be understood and trusted by biological oceanographers.

## **APPROACH**

We are developing species- and life-stage-specific acoustic scattering models of zooplankton found at representative sites in the Gulf of Maine and Georges Bank. These models are created using data from preserved specimens, video, photographs, and scientific illustrations. The acoustic models give scattering strength as a function of frequency and animal species, size, and orientation with respect to

Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE <b>30 AUG 2001</b>		2. REPORT TYPE		3. DATES COVERED <b>00-00-2001 to 00-00-2001</b>	
4. TITLE AND SUBTITLE <b>Advanced Multifrequency Inversion Methods for Classifying Acoustic Scatterers</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>BAE SYSTEMS,,4669 Murphy Canyon Road, Suite 102,,San Diego,,CA,92123</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>Same as Report (SAR)</b>	18. NUMBER OF PAGES <b>6</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

the acoustic beam. We will then assemble model sets for each location that reflect the species present at particular times of year. Methods are being developed for using these model sets, plus net sample data from specific field studies, as ancillary information to improve real-time acoustic classifications of animals and the mathematical inversions used to estimate animal abundance as a function of species. The work is being done as described below in detail.

## Details

We are working with zooplankton species from sites on Georges Bank and in the Gulf of Maine. We are using representative images of the animals using data from the VPR, from other video sources, from photographs of living and dead specimens, and from scientific illustrations.

We then digitize the images to develop acoustic scattering models. These scattering models are developed for specific life-stages or sizes, and describe acoustic backscattering as a function of the acoustic frequency, and the animal's species, size, and orientation with respect to the acoustic beam. Fluid-like animals are modeled using a distorted wave Born approximation (DWBA) approach. Hard-shelled and gas-bearing animals will be modeled as described in Stanton et al., 1998. We may also explore the use of finite element modeling for the hard-shelled and gas-bearing animals. Material properties will be taken from the literature, where applicable (e.g. Greenlaw and Johnson, 1982; Foote, 1990), or possibly from experiments. As the models are completed, they will be provided to the scientific community via the World-Wide Web, along with the Matlab code needed to run them. These models will be very general, permitting the user to predict backscattering at arbitrary acoustic frequencies, animal sizes and orientations, etc.

Currently the inversion algorithms for both TAPS and BIOMAPER II (BIO-optical Multi-frequency Acoustical and Physical Environmental Recorder) calculate biomass as a function of Equivalent Spherical Radius (ESR). Instead of estimating the biomass of *Calanus pacificus*, *Euphausia pacifica*, etc., they estimate the biomass of organisms with ESR = 1.0 mm, 2.0 mm, etc. Using the species lists and corresponding scattering models developed in Years 1 and 2, we hope to replace the ESR-based ranking of biomass with one linked to species or genus. The plan is to develop ways for doing this in a rational and easily presentable way, with the ultimate goal of real-time classification.

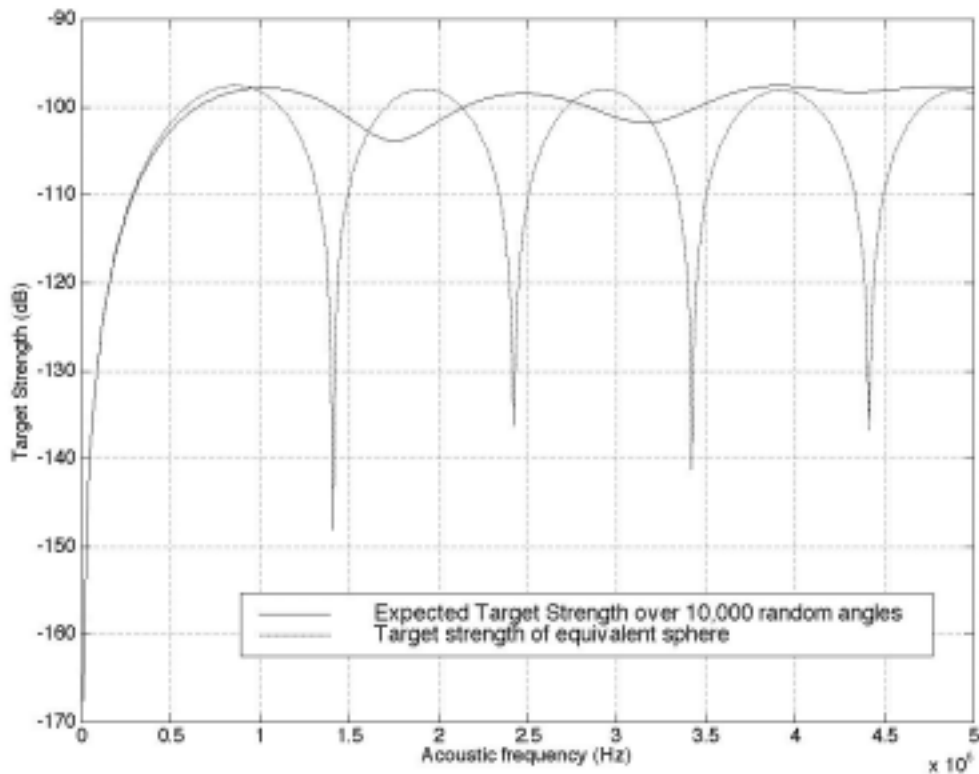
We hope to develop methods to incorporate *a priori* knowledge, either from nets/pumps/video, or from historical information, into the inversions in an attempt to obtain solutions that more accurately reflect the underlying animal distributions in the ocean. Thus, for example, we will not necessarily try to push the solution to be minimum length (low biomass). If we are working in an area where we have *a priori* information concerning the expected species mix, we might choose a solution that attempts to approximate that species mix as closely as possible without disagreeing with the measurements.

## WORK COMPLETED

We have developed DWBA scattering models for copepods belonging to the following genera: *Centropages*, *Clausocalanus*, *Corycaeus*, *Halectinosoma*, and *Oithona*,. Each model has been subjected to acoustic scattering at 10,000 random incidence angles, at frequencies from 10 kHz to 5 MHz in increments of 10 kHz.

## RESULTS

Our results so far are tentative. As expected, predicted backscattering from all animals modeled thus far varies strongly with both orientation and acoustic frequency. We have not yet determined a good way to present backscattering results from 10,000 angles and 500 acoustic frequencies in the same figure. Figure 1 shows a summary of backscattering averaged over the 10,000 angles as a function of acoustic frequency for a 1.8 mm long copepod of genus *Clausocalanus* (ESR = 0.39 mm). Scattering from a fluid sphere of the same ESR is also shown. The effects of averaging the *Clausocalanus* results are seen in the loss of the deep nulls at certain frequencies: at any given scattering angle these nulls present.



**Figure 1. Average backscattering vs. acoustic frequency for a 1.8 mm copepod of genus *Clausocalanus*, compared to the modeled backscattering from a fluid sphere of the same ESR.**

## IMPACTS/APPLICATIONS

The Office of Naval Research has allocated significant resources to the development both of sophisticated acoustic scattering models and of multiple frequency systems like TAPS and BIOMAPER II. This research is the next logical step in merging those two lines of inquiry. The long-range goal of the research is to develop a method that can be tailored to any multifrequency or broadband acoustic system to provide real-time classification of scatterers. Also, the algorithms

developed in this research will be applicable to a variety of problems including, for example, the sizing of suspended sediments.

The goal of biological oceanographers is to be able to say 1) what organisms are present in a given ecosystem, 2) what their abundances are, 3) how they are distributed, and 4) what the factors are that control or affect the distributions. To do this, it is necessary to be able to detect, classify, and count the organisms. At present there are three major approaches to the problems of detecting, classifying and counting zooplankton, loosely described as nets and pumps; optics; and acoustics, each of which has its advantages and drawbacks. We think this research will help integrate the data from these three sampling modalities to give an integrated view of the distribution of animals in the ocean. In particular, we hope to achieve real-time biomass estimates and classification of acoustic scatterers.

The presence, abundance and dynamics of life in the sea at all trophic levels have both direct and indirect impacts on the ability of MCM, ASW, undersea warfare, expeditionary warfare and special ops forces to perform their missions. Specifically, zooplankton and micronekton in the water column control optical properties of interest through grazing on phytoplankton. They also control acoustical parameters both by scattering sound at frequencies used in operational and planned Navy sensors and by transferring energy via the food web to trophic levels that scatter sound at other frequencies used in operational and planned Navy sensors. Moreover, biological phenomena have been identified that affect acoustical scattering from the seabed (bioturbation and volume heterogeneity) and from the sea surface and its environs (suppression of capillary waves and biological production of bubbles). Many of the organisms mentioned above are responsible for much of the bioluminescence in the sea; also they act as controls on bioluminescent organisms both below and above them in the food web. It has therefore become increasingly important to the Navy to be able to know in real time what organisms are present in the water column, and in what quantities. This need has been documented in a variety of symposia, Naval messages, congressional hearings, briefings and scientific meetings.

## **RELATED PROJECTS**

The Stanton lab at the Woods Hole Oceanographic Institution is the premier source of acoustic modeling methods. They are currently developing sophisticated scattering models, including full three-dimensional DWBA models, from which this project will certainly benefit.

The Sound, Oceanography, and Living Marine Resources Program, conducted over the past several years in the Mediterranean Sea with substantial support from the Office of Naval Research, has benefited from modeling support from this project.

The Development and Applications of Technology for Sensing Zooplankton program, spearheaded by D. V. Holliday, C. F. Greenlaw, and D. E. McGehee at BAE SYSTEMS, conducts pioneering work in multi-static acoustic scattering from zooplankton (measurement of sound scattered in all directions by a zooplankter, not just the sound backscattered to the transmitter). The backscattering-based results from the present effort are expected to dovetail with the multi-static results. For example, it is hoped that the backscattering models developed in this effort may eventually be extended into multi-static scattering models. Also, a desired outcome of the multi-static scattering effort is the ability to estimate acoustic material properties of the scatterers based on the measurements. These material property measurements of individual zooplankters will provide extremely valuable data for future backscattering modeling efforts.

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